

Measurement of cluster elongation and charge in a pixel detector of $10\ \mu\text{m}$ pitch at sub-GeV energies

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Abstract: We present measurements of elongation and cluster charge using MIMOSA-18 MAPS pixel matrix with $10\ \mu\text{m}$ pixel pitch, using electron test beams of energies ranging from 15 to 500 MeV. We observe energy dependence of cluster charge and elongation for large incident angles.

In our recent publications [1],[2] we presented results of our studies of cluster shapes in a Monolithic Active Pixel Sensor (MAPS) MIMOSA-5 of $17\ \mu\text{m}$ pixel pitch. The MAPS pixel arrays have been considered, among others, as a technology for a vertex detector at the future International Linear Collider [3],[4]. The vertex detector will be exposed to a significant background of e^+e^- pairs from the beamstrahlung process. These electron-positron pairs enter the pixel matrices and create clusters additional to those due to secondary particles from beam collisions [5], [6]. A MIMOSA-5 detector was exposed to 1 and 6 GeV beams of electrons incident at various angles θ . The aim of these studies was to measure magnitude of cluster elongation and precision of its azimuthal angle determination as functions of the angle θ . In this paper we present measurements of elongation and cluster charge using the MIMOSA-18 pixel matrix with $10\ \mu\text{m}$ pixel pitch, using electron test beams of lower energies, as compared to previous measurements, and several energy settings, at MAMI (Mainzer Mikrotron at Johannes Gutenberg Universität Mainz) and INFN Frascati.

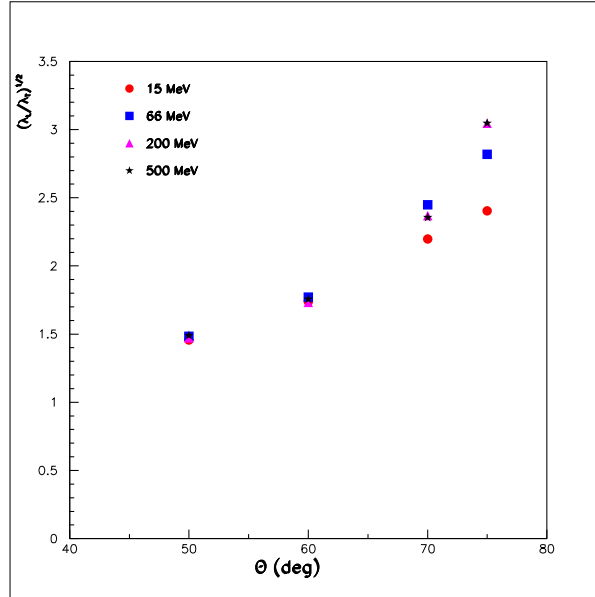


Figure 1: Measured ratio of the longitudinal and transverse dimensions of a cluster as a function of the θ angle for several beam energies.

Monolithic Active Pixel Sensor, MAPS, consists of three layers: a highly doped p-type substrate, a partially depleted p-type epitaxial layer (sensitive volume) and a p-well where the collecting diodes of the n-type are implemented. Charge carriers, created during passage of an ionising particle, diffuse inside the epitaxial layer. Potential barriers, appearing on the layer boundaries due to different doping levels, act to confine electrons within the sensitive volume until they are collected by the diodes. Studies show that the MAPS matrices may have spatial resolution of the order a few μm , almost 100% detection efficiency, possess good resistance to radiation [7],[8]. We have used the MIMOSA-18¹ MAPS prototype for the present studies. The device was fabricated in the AMS 0.35 μm opto CMOS technology. The epitaxial layer, which constitutes the sensitive volume of the detector, was 14 μm thick. We have used a module of 256×256 pixels. The MIMOSA-18 matrix was mounted on an adjustable mechanical support, enabling rotations, and was kept at room temperature. The matrix was oriented manually to the desired angles before each data taking run using the angular scale with an accuracy of approximately $\pm 1^\circ$. The matrix was exposed to electron test beams as follows: 15 MeV at MAMI and 66, 100, 150, 200, 400, 500 MeV at INFN Frascati. The measurements were done for various orientations of the matrix w.r.t. the beam. The lowest energy (15 MeV) falls in the energy range of beamstrahlung electrons in the planned ILC collider. Clusters of pixels were reconstructed according to the following procedure. First, pedestals and noise levels, were evaluated for each pixel. A cluster was defined as a set of pixels, each with charge to noise ratio greater than 3, with exception of the seed, i.e. the pixel carrying the largest charge, where this ratio was required to be greater than 8. Pixels in a cluster had at least one common edge with other pixels belonging to

¹Minimum Ionizing particle MOS Active pixel sensor

cluster (one-pixel clusters were rejected). It was assumed that the charge-weighted centre of gravity of a cluster coincided with the track position at the matrix surface. Particles passing through the detector at low incident angles leave statistically round clusters. Since in a MAPS detector the charge transport is by diffusion, it is expected that clusters arising from sufficiently inclined tracks should be elongated in the track direction projected on the pixel plane while unaltered in the perpendicular direction. We have measured the magnitude of the elongation as a function of the incident angle θ for various energies.

Longitudinal and transverse dimensions of a cluster may be obtained from diagonalising the charge distribution matrix defined as:

$$\begin{pmatrix} \sum_{i=1}^{N_c} \frac{q_i}{Q} (x_i - \bar{x})^2 & \sum_{i=1}^{N_c} \frac{q_i}{Q} (x_i - \bar{x})(y_i - \bar{y}) \\ \sum_{i=1}^{N_c} \frac{q_i}{Q} (x_i - \bar{x})(y_i - \bar{y}) & \sum_{i=1}^{N_c} \frac{q_i}{Q} (y_i - \bar{y})^2 \end{pmatrix}, \quad (1)$$

where Q is the cluster charge, q_i is the charge of the i -th pixel, x_i, y_i are its positions in the MIMOSA-18 coordinates system and \bar{x}, \bar{y} are the coordinates of the charge-weighted centre of gravity of the cluster:

$$\bar{x} = \sum_{i=1}^{N_c} \frac{q_i}{Q} x_i, \quad \bar{y} = \sum_{i=1}^{N_c} \frac{q_i}{Q} y_i. \quad (2)$$

Diagonalisation of (1) allows to determine the eigenvectors and the respective eigenvalues, λ_L and λ_T . The ratio $\sqrt{\lambda_L/\lambda_T}$ is a measure of cluster elongation. The measured dependence of this quantity on the incident angle θ is shown in Fig. 1. Cluster elongation depends strongly on θ for sufficiently large values. While no dependence of elongation on track energy was seen for GeV-energy tracks [1], we do observe this dependence for energies in the range of the present measurement, approximately for $\theta > 60^\circ$. Tracks incident at low angles do not form elongated clusters because the charge is symmetrically distributed around the seed.

The charge of a cluster is obtained by summing charges deposited in pixels belonging to it. The total charge is described by the Landau distribution with the most probable value, MPV, depending on the track energy and the θ angle. Dependence of the MPV on track energy and θ is shown in Figs. 2 and 3, respectively. We observe that the larger θ , the stronger is the energy dependence of the MPV. In summary, we have measured cluster shapes and charges using the MIMOSA-18 MAPS detector exposed to 15 MeV at MAMI and 66, 100, 150, 200, 400, 500 MeV at INFN Frascati. Cluster elongation was measured for various orientations of the pixel matrix w.r.t. the beam axis (angle θ). The results may be summarised as follows: (i) clusters can be reliably reconstructed as elongated for $\theta > 60^\circ$ and the effect grows rapidly with increasing θ ; (ii) energy dependence of the above effect is observed for $\theta > 60^\circ$ where elongation increases significantly with energy in the sub-GeV region (no such effect was present for 1 and 6 GeV tracks); (iii) little energy dependence of the cluster charge is observed for round clusters ($\theta < 60^\circ$) while there is a significant energy dependence for elongated clusters ($\theta > 60^\circ$); clusters arising from beamstrahlung electron tracks carry on average less charge than those from interaction secondaries.

Acknowledgements

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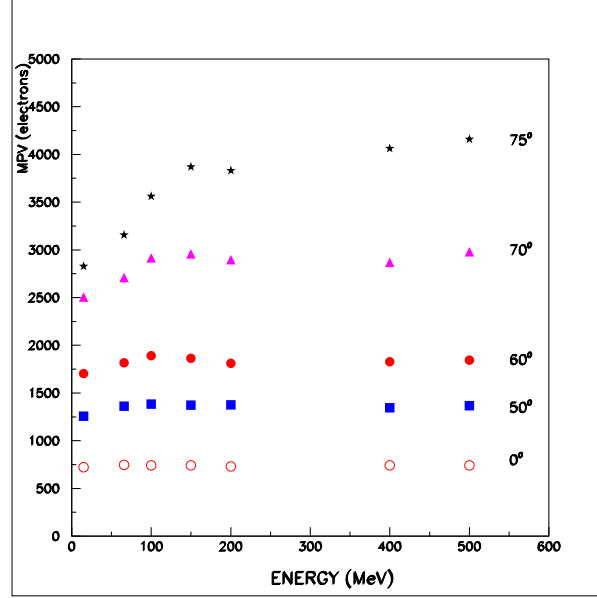


Figure 2: MPV of the Landau charge distribution as a function of beam energy for several incident angle settings, θ .

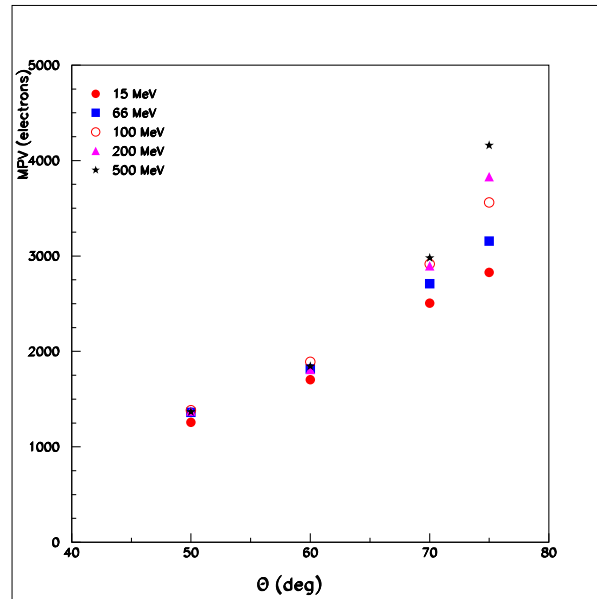


Figure 3: MPV of the Landau charge distribution as a function of incident angle, θ , for several beam energies.

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